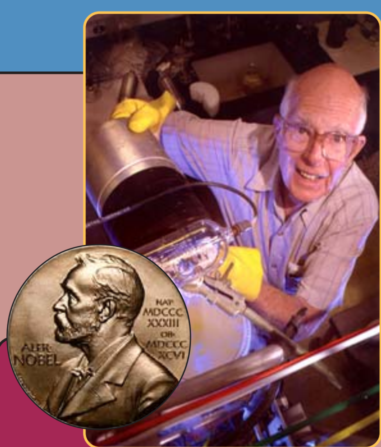
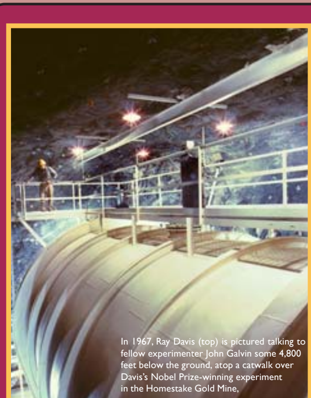
Brookhaven's Raymond Davis, Jr. Wins the 2002 Nobel Prize in Physics



Raymond Davis, Jr. earned a B.S. and an M.S. from the University of Maryland in 1937 and 1940, respectively, and a Ph.D. in physical chemistry from Yale University in 1942. After his 1942-46 service in the U.S. Army Air Force and two years at Monsanto Chemical Company, he joined Brookhaven's Chemistry Department in 1948. He received tenure in 1956 and was named senior chemist in 1964.

From 1971 to 1973, Davis was a member of the National Aeronautics and Space Administration's Lunar Sample Review Board, involved in the analysis of lunar dust and rocks collected by Apollo 11 on the National Aeronautics and Space Administration's historic first flight to the moon. Davis retired from Brookhaven in 1984, but has a research collaborator appointment in the Chemistry Department. In 1985, he joined the University of Pennsylvania as a research professor, to continue experiments at the Homestake Gold Mine.

A member of the National Academy of Sciences and the American Academy of Arts and Sciences, Davis has won numerous scientific awards, including: the 1978 Cyrus B. Comstock Prize from the National Academy of Sciences; the 1988 Tom W. Bonner Prize from the American Physical Society; the 1992 W.K.H. Panofsky Prize, also from APS; the 1999 Bruno Pontecorvo Prize from the Joint Institute for Nuclear Research in Dubna, Russia; the 2000 Wolf Prize in Physics, which he shared with Masatoshi Koshiba, University of Tokyo, Japan; and the 2002 U.S. National Medal of Science.



In 1967, Ray Davis (top) is pictured talking to fellow experimenter John Galvin some 4,800 feet below the ground, atop a catwalk over Davis's Nobel Prize-winning experiment in the Homestake Gold Mine, in Lead, South Dakota.

Davis constructed his first solar neutrino detector in 1961, some 2,300 feet below ground in a limestone mine in Ohio. Building on this experience and testing prototype equipment in the Laboratory's swimming pool, he mounted a full-scale experiment in the Homestake Gold Mine, South Dakota.

The experimental apparatus consisted of 100,000 gallons of tetrachloroethylene, a dry cleaning fluid, in a 20-foot-in-diameter by 48-foot-long tank; a pair of pumps to circulate helium through the liquid; and a small control room building — all located some 4,800 feet below the surface.

ONE-THIRD OF THE NEUTRINOS

Throughout the course of this research, Davis consistently found only one-third of the neutrinos predicted by standard solar theories. For nearly three decades, physicists tried to resolve what they called the solar neutrino puzzle.

Experiments in the 1990s using different detectors around the world eventually confirmed the discrepancy in the number of solar neutrinos that Davis detected. Davis's lower-than expected neutrino detection rate is now accepted by the international science community as the first evidence that neutrinos have the ability to change from one of the three known neutrino types into another.

This characteristic, called neutrino oscillation, implies that the neutrino has mass, a property that is not included in the current standard model of elementary particles. Davis's detector was sensitive to only one type of the neutrino, the electron-type neutrino which is produced in the Sun. If these neutrinos had changed into the other types, then they would have seemed to have disappeared.

Instrumentation Research & Development

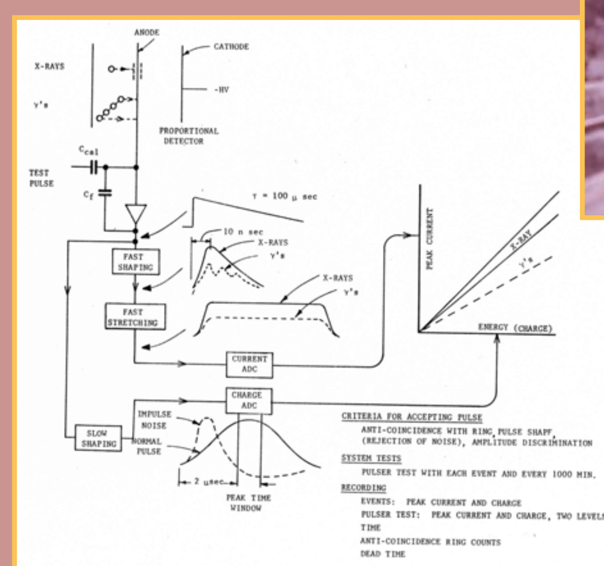
To detect solar neutrinos directly in his Homestake Mine experiment, Ray Davis made use of a neutrino capture reaction, whereby, when an atom of chlorine-37 captures a neutrino, it becomes argon-37. In the subsequent decay of argon-37 back to chlorine-37, Auger electrons are emitted with a total energy of 2.8 kilo electron volts (keV), which Davis measured using a proportional counter.

During the first three years of the now Nobel-prize winning experiment, a "single parameter" technique was employed to detect the Auger electrons. While this technique did produce an upper limit for the neutrino capture rate, it could not distinguish between the point-like ionization produced by the Auger electrons and the extended ionization tracks of more energetic electrons arising from gamma-ray and other background events.

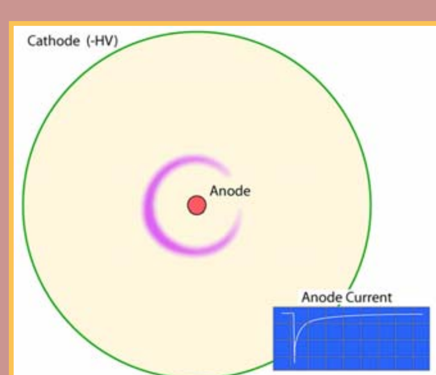
To solve this problem, Veljko Radeka and Lee Rogers of Brookhaven's Instrumentation Division employed a two-parameter technique that rejected between 85 and 98 percent of the background-radiation events. To apply this "pulse rise-time" method to Davis's experiment, the Instrumentation researchers developed low noise amplification and signal processing on a nanosecond time scale. The new detection system was introduced in 1970, and, after one year of its operation, the first clear signal of Argon-37 decay was observed.

"The pulse rise-time system development gave the Homestake experiment new life," thanks to instrumentation research and development at Brookhaven Lab.
-Raymond Davis, Jr.

The very small number of argon-37 atoms created by solar neutrino capture are first extracted from the large tank (background) containing about 10^{31} chlorine atoms and then transferred into a proportional counter (foreground) with an active volume of approximately 0.5 cubic centimeters.

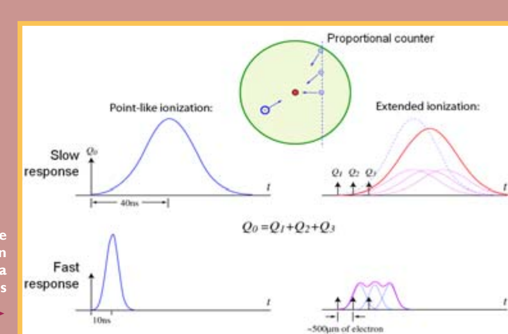


Readout system diagram for the Homestake Mine neutrino experiment.

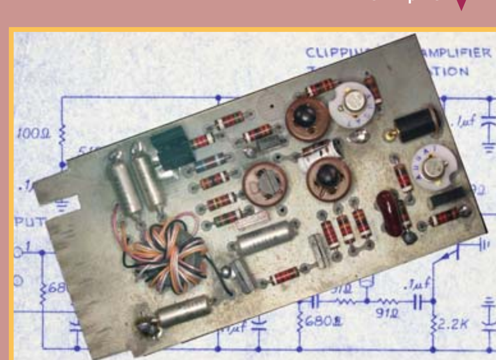


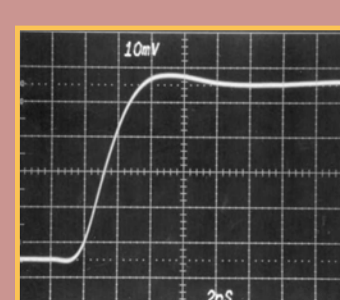
Argon-37 decays back to chlorine-37 with a half-life of 35 days. The decay is followed by the emission of Auger electrons with a total energy of 2.8 keV. The Auger electrons lose all of their energy over a very short distance in the counter gas and produce a point-like ionization. The background events, mostly due to gamma rays, produce much more energetic electrons which result in extended ionization tracks. The charge, due to ionization, is amplified by an avalanche process near the center wire (anode) and produces signals.

On a very short time scale of a few nanoseconds, there is a clear distinction in the signal waveforms between point-like and extended ionization. This provides a unique signature for distinction of argon-37 decays against background radiation.



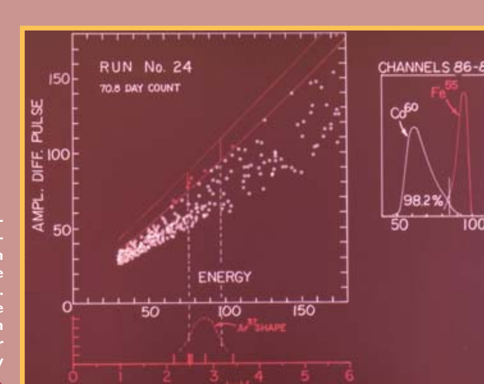
Pre-Amplifier





Pre-Amplifier response to a point ionization from Auger electrons.

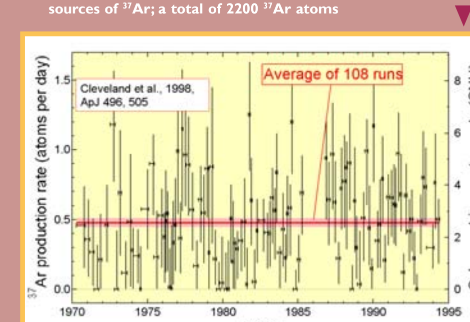
The electronic counting system, developed to emphasize the distinction between argon-37 decays and background radiation, displays the peak signal current in the counter ("Ampl. Diff. Pulse") as a function of the energy deposited in the counter for each detected event. Red circles indicate argon-37- like events, and white circles the background-like events. The discrimination properties are evaluated by illuminating the counter with iron-55 x-rays for point-like ionization, and by cobalt-60 gamma rays for extended ionization.



Lee C. Rogers of Instrumentation Division seen here testing some of the electronics used in the Homestake Mine experiment.

The two-parameter-signature technique (known also as "the pulse rise-time method") made possible rejection of ~85-98% of background radiation events. A challenge in application of this technique was to develop low noise amplification and signal processing on nanosecond time scale. The single parameter, i.e., the energy measurement, allowed only an upper limit for the neutrino capture rate to be determined, which was dominated by the background radiation. The new detection system was introduced in 1970, and after one year, and with increasing confidence after several years, a clear solar neutrino signal was observed. In the words of Ray Davis: "The pulse rise-time system development gave the Homestake experiment a new life".

Summary of all data, after correction for all known nonsolar sources of ^{37}Ar; a total of 2200 ^{37}Ar atoms



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